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(54) **SUBSTRATE, METHOD OF PRODUCING SUBSTRATE SUPERCONDUCTING WIRE AND METHOD OF PRODUCING OF SUPERCONDUCTING WIRE**

SUBSTRAT, VERFAHREN ZUR HERSTELLUNG EINES SUPRALEITENDEN DRAHTS EINES SUBSTRATS UND VERFAHREN ZUR HERSTELLUNG EINES SUPRALEITENDEN DRAHTS

SUBSTRAT, PROCÉDÉ DE FABRICATION DU SUBSTRAT, MATÉRIAU DE CÂBLE ÉLECTRIQUE SUPRACONDUCTEUR ET PROCÉDÉ DE FABRICATION DUDIT MATÉRIAU

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Description

TECHNICAL FIELD

[0001] The present invention relates to a substrate, a method of producing a substrate, a superconducting wire, and a method of producing a superconducting wire.

BACKGROUND ART

[0002] Since the discovery of high-temperature superconductors, development in high-temperature superconducting wire is carried out actively in view of the application to power apparatus such as a cable, magnet, current-limiting device, and the like. The high-temperature superconducting wire is roughly classified into two types, i.e. a bismuth type silver sheath wire and a RE 123 type thin film wire (RE = rare earth element).

[0003] The RE 123 type thin film superconducting wire has raised hopes for a high-temperature superconducting wire of the next generation based on the advantages of: (1) the critical current density at the liquid nitrogen temperature (77.3K) exhibits the performance of approximately 10^6A/cm^2 that is two orders of magnitude greater as compared with the bismuth type silver sheath wire; and (2) the critical current density under magnetic field is high.

[0004] As a general structure of a thin film superconducting wire, a thin intermediate layer of ceramic or of nickel and ceramic layers according to US 2008/0261072 A1 is formed on a metal substrate, and a superconducting layer is formed thereon. In order to draw out superior superconducting properties for a thin film superconducting wire, the crystal orientation of the superconducting layer must be arranged in three dimensions. To this end, a thin film having high orientation must be produced for the aforementioned thin film intermediate layer.

[0005] Japanese Patent Laying-Open No. 2005-1935 (Patent Literature 1) discloses a method including the steps of removing an oxide layer located on the surface of an oriented metal substrate, and epitaxial growth of a thin film such as an intermediate layer and a superconducting layer while maintaining the biaxial orientation of the oriented metal substrate.

CITATION LIST

PATENT LITERATURE

[0006] PTL 1: Japanese Patent Laying-Open No. 2005-1935

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0007] When a superconducting wire is produced using a ferromagnetic body such as Ni for an oriented metal substrate, as disclosed in Patent Literature 1, and current is conducted to the obtained superconducting wire, there was a problem that the saturation magnetization of the substrate is great and the AC loss caused by hysteresis loss is increased.

[0008] Therefore, an object of the present invention is to provide a substrate that allows the AC loss of a superconducting wire to be reduced, a method of producing a substrate, a superconducting wire, and a method of producing a superconducting wire.

SOLUTION TO PROBLEM

[0009] A substrate of the present invention is defined in claim 1 and includes a copper layer, an alloy layer containing copper and nickel, formed on the copper layer, a nickel layer formed on the alloy layer, and an intermediate layer formed on the nickel layer. The concentration of nickel in the alloy layer at the interface between the alloy layer and the nickel layer is greater than the concentration of nickel in the alloy layer at the interface between the alloy layer and the copper layer.

[0010] Preferably in the substrate of the present invention, the concentration of nickel in the alloy layer is monotonically decreased from the interface between the alloy layer and the nickel layer towards the interface between the alloy layer and the copper layer.

[0011] A method of producing a substrate of the present invention is defined in claim 3 and includes the steps of: preparing a substrate having a nickel layer formed on a copper layer through plating, alloying a portion of the nickel layer while leaving a remaining portion of the nickel layer; and epitaxial-growing an intermediate layer on the nickel layer after the step of alloying the nickel layer.

[0012] A superconducting wire of the present invention is defined in claim 5 and includes a copper layer, an alloy layer containing copper and nickel, formed on the copper layer, a nickel layer formed on the alloy layer, an intermediate layer formed on the nickel layer, and a superconducting layer formed on the intermediate layer. The concentration of nickel in the alloy layer at the interface between the alloy layer and the nickel layer is greater than the concentration of nickel in the alloy layer at the interface between the alloy layer and the copper layer.
[0013] Preferably in the superconducting wire of the present invention, the concentration of nickel in the alloy layer is monotonically decreased from the interface between the alloy layer and the nickel layer towards the interface between the alloy layer and the copper layer.
[0014] A method of producing a superconducting wire of the present invention is defined in claim 7 and includes the steps of: preparing a substrate having a nickel layer formed on a copper layer through plating, alloying a portion of the nickel layer while leaving a remaining portion of the nickel layer; epitaxial-growing an intermediate layer on the nickel layer after the step of alloying the nickel layer, and forming a superconducting layer on the intermediate layer.
[0015] According to a substrate, a method of producing a substrate, a superconducting wire, and a method of producing a superconducting wire of the present invention, some of the nickel in the substrate is alloyed to be rendered non-magnetic. Accordingly, the hysteresis loss at the substrate is decreased, allowing the AC loss of the superconducting wire to be reduced.
[0016] Preferably in the method of producing a substrate of the present invention, the step of alloying the nickel layer is carried out under reduced pressure absent of hydrogen gas.
[0017] Preferable in the method of producing a superconducting wire of the present invention, the step of alloying the nickel layer is carried out under reduced pressure absent of hydrogen gas.
[0018] By carrying out the step of alloying the nickel layer under reduced pressure absent of hydrogen gas, the oxide layer at the Ni surface is left until just before formation of the intermediate layer, and reduced during formation of the intermediate layer. Accordingly, Ni having favorable matching lattice with the intermediate layer is exposed at the surface while H_2O is present in the proximity of the substrate. Therefore, oxygen loss of the metal oxide that is the intermediate layer can be prevented to facilitate orientation.

ADVANTAGEOUS EFFECT OF INVENTION

[0019] According to the present invention, a substrate and a superconducting wire that can reduce AC loss of the superconducting wire can be obtained.

BRIEF DESCRIPTION OF DRAWINGS

[0020]

Fig. 1 is a schematic sectional view of a substrate according to an embodiment of the present invention.
Fig. 2 is a schematic sectional view of a superconducting wire according to an embodiment of the present invention.
Fig. 3 is a schematic sectional view to describe a method of producing a substrate and a superconducting wire according to an embodiment of the present invention.
Fig. 4 is a graph representing the nickel concentration in an alloy layer of a substrate or superconducting wire according to an embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

[0021] Embodiments of the present invention will be described hereinafter with reference to the drawings. In the drawings, the same or corresponding elements have the same reference characters allotted, and description thereof will not be repeated.

<First Embodiment>

(Substrate)

[0022] Fig. 1 is a schematic sectional view of a substrate 1 according to an embodiment of the present invention. Referring to Fig. 1, substrate 1 according to an embodiment of the present invention includes a copper layer (hereinafter, also referred to as "Cu layer") 2, an alloy layer 3 containing copper and nickel, formed on copper layer 2, a nickel layer 4 (hereinafter, also referred to as "Ni layer") formed on alloy layer 3, and an intermediate layer 5 formed on nickel layer 4.
[0023] Substrate 1 may take the shape of a relatively lengthy tape.

(Copper Layer)

[0024] Cu layer 2 is suitable for an oriented substrate since Cu atoms are in biaxial orientation. A "biaxial orientation" includes, not only a complete biaxial orientation, but also the case where the angle of deviation of the crystal axis is less than or equal to 25°. Moreover, the orientation direction preferably corresponds to the case where the <100> axis is in a direction perpendicular to the substrate face and the <010> axis is in the direction of the length of the substrate.
[0025] Cu layer 2 can also be stacked on another metal or alloy. For example, Cu layer 2 can be provided on stainless steel that is a material of high strength (hereinafter, also referred to as SUS).
[0026] Cu layer 2 may take the shape of a relatively lengthy tape.
[0027] The thickness of Cu layer 2 is 1 to 18 μm, for example.

(Alloy Layer)

[0028] Alloy layer 3 is a non-magnetic metal containing nickel and copper. Preferably, alloy layer 3 is oriented.
[0029] The saturation magnetization of alloy layer 3 is smaller than the saturation magnetization of simple Ni. Namely, there is the case where the flux density is 0T, and the case where the flux density exceeds 0T and is lower than the flux density of simple Ni.
[0030] The magnetism of alloy layer 3 is smaller than the magnetism of simple Ni. Namely, there is the case where the maximum energy (BHmax) is 0 J/m^3, and the case where the maximum energy exceeds 0 J/m^3 and is smaller than the maximum energy of simple Ni.
[0031] Alloy layer 3 has an Ni concentration distribution. Specifically, the concentration of nickel in the alloy layer at the interface between the alloy layer and the nickel layer indicated by A in Figs. 1 and 2 is greater than the concentration of nickel in the alloy layer at the interface between the alloy layer and the copper layer indicated by B in Figs. 1 and 2.
[0032] In alloy layer 3, the concentration of Ni in alloy layer 3 is preferably monotonically decreasing from the interface between alloy layer 3 and Ni layer 4 indicated by A in Figs. 1 and 2 towards the interface between alloy layer 3 and Cu layer 2 indicated by B in Figs. 1 and 2.
[0033] Monotonic decrease will be described with reference to Fig. 4. In Fig. 4 (a) representing an example of monotonic decrease, the Ni concentration in alloy layer 3 always decreases from the interface between alloy layer 3 and Ni layer 4 indicated by A towards the interface between alloy layer 3 and Cu layer 2 indicated by B, as shown in c, d and e. Referring to Fig. 4 (b) representing another example of monotonic decrease, the concentration of Ni in alloy layer 3 is the same or decreases from the interface between alloy layer 3 and Ni layer 4 indicated by A towards the interface between alloy layer 3 and Cu layer 2 indicated by B, as shown by f. In other words, "monotonic decrease" means that any region where the Ni concentration increases from the interface between alloy layer 3 and Ni layer 4 indicated by A towards the interface between alloy layer 3 and Cu layer 2 indicated by B is not included.
[0034] Alloy layer 3 has a thickness of 1.0 to 2.1 μm.

(Nickel Layer)

[0035] Ni layer 4 serves to prevent oxidation during formation of intermediate layer 5.
In the case where Cu layer 2 is oriented, Ni layer 4 is also oriented.
[0036] Ni layer 4 preferably has a thickness of 0.3 to 1.5 μm.

(Intermediate Layer)

[0037] Intermediate layer 5 serves to have superconducting layer 6 formed on its surface. Intermediate layer 5 is formed of one or more layers. In the case where intermediate layer 5 is formed of a plurality of layers, each layer constituting intermediate layer 5 may be made of a substance differing from each other.
[0038] For intermediate layer 5, a metal oxide having at least one type of metal element with a crystal structure of the pyrochlore, fluorite, rock salt or perovskite type is adopted. Specifically, rare earth element oxide such as CeO_2, YSZ (Yttria Stabilized Zirconia), BZO ($BaZrO_3$), STO ($SrTiO_3$), Al_2O_3, $YAlO_3$, MgO, Ln-M-O based compound (Ln is one or more type of lanthanoid element, M is one or more type of element selected from Sr, Zr and Ga, and O is oxygen) can be cited. Such oxide serves to alleviate the difference in the crystal constant and crystal orientation between Cu layer 2 that is the oriented metal substrate and superconducting layer 6 formed on intermediate layer 5, and prevents the flow out of metal atoms from Cu layer 2 towards superconducting layer 6. CeO_2, for example, can be cited for such a material.

<Second Embodiment>

(Superconducting Wire)

[0039] Fig. 2 is a schematic sectional view of superconducting wire 7 according to an embodiment of the present invention. Referring to Fig. 2, superconducting wire 7 according to an embodiment of the present invention includes a copper layer 2, an alloy layer 3 containing copper and nickel, formed on copper layer 2, a nickel layer 4 formed on alloy layer 3, an intermediate layer 5 formed on nickel layer 4, and a superconducting layer 6 formed on intermediate layer 5.

[0040] Superconducting wire 7 may have the shape of a relatively lengthy tape.

[0041] Copper layer 2, alloy layer 3, nickel layer 4, and intermediate layer 5 in superconducting wire 7 are similar to those adopted for substrate 1.

(Superconducting Layer)

[0042] Superconducting layer 6 has the shape of a relatively lengthy tape. Superconducting layer 6 is a superconductor or the like represented by $REBa_2Cu_3O_y$(y is 6 - 8, more preferably substantially 7; RE implies a rare earth element such as Y (yttrium), or Gd (gadolinium), Sm (samarium), Ho (holmium)). Preferably, superconducting layer 6 is formed of GdBCO, for example. GdBCO is represented as $GdBa_2Cu_3O_y$ (y is 6 - 8, more preferably substantially 7).

[0043] Superconducting wire 7 may further include a protection layer (not shown) formed on superconducting layer 6. The protection layer protects superconducting layer 6, and is the contact region with an external electrode. The protection layer is not particularly limited as long as it has high conductivity. Preferably, Ag, Au, Pt, Al, or an alloy thereof is adopted.

<Third Embodiment>

(Method of Producing Substrate)

[0044] Fig. 3 is a schematic sectional view to describe a method of producing substrate 1 and superconducting wire 7 according to an embodiment of the present invention. Referring to Fig. 3, a method of producing substrate 1 according to an embodiment of the present invention includes the steps of preparing a substrate having formed on Cu layer 2 shown in Fig. 3 (a) an Ni layer 4 through plating, as shown in Fig. 3 (b); alloying a portion of Ni layer 4 while leaving the remaining portion of Ni layer 4, as shown in Fig. 3 (c); and epitaxial-growing an intermediate layer 5 on Ni layer 4, as shown in Fig. 3 (d), after the step of alloying Ni layer 4. Furthermore, the method of producing superconducting wire 7 according to an embodiment of the present invention further includes the step of forming a superconducting layer 6 on intermediate layer 5, as shown in Fig. 3 (e).

(Step of Forming Nickel Layer)

[0045] As shown in Figs. 3 (a) and (b), a substrate is prepared, having Ni layer 4a formed on Cu layer 2 through plating. The plating method includes, for example, an electrolytic nickel plating process carried out on Cu layer 2, for example, in a solution containing nickel chloride, nickel sulfate, or the like.

[0046] As shown in Fig. 3 (b), the thickness of Ni layer 4 formed on Cu layer 2 through plating is preferably 1.3 to 3.6 μm, more preferably 1.3 to 3.0 μm. In the case where the thickness is greater than or equal to 1.3 μm, diffusion of all the Ni atoms to Cu layer 2 can be suppressed even if heat of approximately 800-1000°C is applied in the step of alloying a portion of Ni layer 4 while leaving the remaining portion of Ni layer 4, as will be described afterwards. Accordingly, the function of Ni layer 4, not readily oxidized, and having a favorable matching lattice with intermediate layer 5, can be exhibited effectively. In the case where the thickness is less than or equal to 3.6 μm, the Ni constituting Ni layer 4 will readily diffuse to Cu layer 2 in the alloying step to facilitate alloying effectively.

(Step of Alloying)

[0047] As shown in Fig. 3 (c), one portion of Ni layer 4 is alloyed while leaving the remaining portion of Ni layer 4. By this step, Ni constituting Ni layer 4 and Cu constituting Cu layer 2 are alloyed to allow an alloy layer 3 including Cu-Ni alloy to be formed. The magnetism of Cu-Ni alloy is lower than that of simple Ni. Therefore, in the case where superconducting wire 7 is produced using substrate 1 including alloy layer 3, concentration of the magnetic field towards the end region in the width direction of superconducting wire 7 can be alleviated. Accordingly, the magnetic field affecting the current flowing through superconducting wire 7 can be reduced, allowing reduction in AC loss of the superconducting wire.

[0048] Furthermore, since a portion including the surface of Ni layer 4 is left, orientation of Ni layer 4 can be maintained.

[0049] The step of alloying nickel layer 4 is preferably carried out under reduced pressure, absent of hydrogen gas. For the atmosphere gas, Ar, N_2, for example, or the like, can be used. Reduced pressure is of a level lower than the atmospheric pressure, preferably 0.1 to 10 Pa, for example.

[0050] The step of alloying nickel layer 4 is carried out by subjecting Ni layer 4 to thermal treatment at the temperature of 800-1000°C. If the temperature is below 800°C, alloying of nickel will not proceed. Sufficient effect in reducing magnetism cannot be achieved. If the temperature exceeds 1000°C, Ni and Cu will be completely diffused to be alloyed, causing diffusion of Cu to the surface of the Ni layer. Since Cu is readily oxidized, the orientation at the surface of Ni layer 4 cannot be improved.

[0051] If the duration of thermal treatment is less than 15 minutes, alloying will not proceed sufficiently. The effect of reducing magnetism cannot be expected. If the duration exceeds 25 minutes, Ni and Cu will be completely diffused to be alloyed, causing diffusion of Cu to the surface of the Ni layer. Since Cu is readily oxidized, the orientation at the surface of Ni layer 4 cannot be improved.

(Step of Epitaxial-growing Intermediate Layer)

[0052] As shown in Fig. 3 (d), intermediate layer 5 is deposited on Ni layer 4 epitaxially to obtain substrate 1. The method of forming a thin film oxide qualified as intermediate layer 5 is not particularly limited as long as the object of the present invention is not impaired. For example, sputtering, EBD (Electron Beam Deposition), PLD (Pulse Laser Deposition), thermal deposition or the like can be adopted.

[0053] For example, by epitaxial-growing a CeO_2 thin film as intermediate layer 5 on biaxial oriented Ni layer 4 having the <100> axis in a direction perpendicular to the substrate face and the <010> axis in the length direction of the substrate after the alloying step, a CeO_2 thin film having the <100> axis oriented perpendicular to the substrate face and the <011> axis oriented in the length direction of the substrate is formed. Thus, a CeO_2 thin film having high biaxial orientation can be obtained.

[0054] In the case where the intermediate layer is formed of a plurality of layers, the orientation can be maintained by depositing the second intermediate layer epitaxially on the first intermediate layer, for example.

<Fourth Embodiment>

(Method of Producing Superconducting Wire)

[0055] Fig. 3 is a schematic sectional view to describe a method of producing substrate 1 and superconducting wire 7 according to an embodiment of the present invention. Referring to Fig. 3, the method of producing superconducting wire 7 according to an embodiment of the present invention includes the steps of preparing a substrate having formed on Cu layer 2 shown in Fig. 3 (a) an Ni layer 4 through plating, as shown in Fig. 3 (b): alloying a portion of Ni layer 4 while leaving the remaining portion of Ni layer 4, as shown in Fig. 3 (c); epitaxial-growing an intermediate layer 5 on Ni layer 4, as shown in Fig. 3 (d), after the step of alloying Ni layer 4; and forming a superconducting layer 6 on intermediate layer 5, as shown in Fig. 3 (e).

[0056] The step of forming a nickel layer, the step of alloying, and the step of epitaxial-growing an intermediate layer are similar to those in the method of producing a substrate.

<Formation of Superconducting Layer>

[0057] In the case where superconducting layer 6 is formed on intermediate layer 5 of substrate 1 obtained according to the fourth embodiment, for example, a superconducting layer 6 of high biaxial orientation can be obtained since intermediate layer 5 has favorable orientation.

[0058] The method of forming a thin oxide film that will become superconducting layer 6 is not particularly limited as long as the object of the present invention is not impaired. Preferably, the PLD method, MOD (Metal Organic Deposition), MOCVD (Metal Organic Chemical Vapor Deposition), and the like can be adopted.

[0059] Furthermore, for the purpose of protecting superconducting layer 6, a protection layer (not shown) can be formed on superconducting layer 6, as necessary. The method of forming a protection layer preferably includes, but not particularly limited to, sputtering, EBD, PLD, thermal deposition, MOD, MOCVD, plating, and the like.

EXAMPLE

(Example 1)

[0060] First, a substrate having a 18 μm-thick Cu layer on a 100 μm-thick SUS substrate was prepared. The substrate including the Cu layer was subjected to electrolytic nickel plating in a solution containing nickel chloride to form an Ni layer having a thickness of 2.4 μm.

[0061] The Ni layer was subjected to thermal treatment for 15 minutes using Ar gas under the atmosphere of 0.1 Pa to 10 Pa in pressure at the thermal treatment temperature of 850°C- 1000°C. Thus, a Cu-Ni alloy layer was formed from the Ni layer and Cu layer.

[0062] Immediately thereafter, sputtering was carried out using a mixture of H_2 gas and Ar gas as the reducing gas (composition: 3 mole % of H_2 gas, 97 mole % of Ar gas) under the atmosphere of 5.2 Pa in pressure and at the substrate temperature of 700°C to form on the Ni layer a CeO_2 thin film to a thickness of 0.15 μm as an intermediate layer. On that CeO_2 thin film, a YSZ thin film was formed to a thickness of 0.26 μm as the second intermediate layer under the atmosphere of 2.6 Pa in pressure and at the substrate temperature of 900°C with the mixture gas modified (composition: 0.5 mole % of O_2 gas, 99.5 mole % of Ar gas). Finally, a CeO_2 thin film was formed to a thickness of 0.05 μm as the third intermediate layer on the YSZ layer under the atmosphere of 2.6 Pa in pressure and at the substrate temperature of 800°C with the mixture gas modified (composition: 1 mole % of O_2 gas, 99 mole % of Ar gas). Thus, the substrate of Example 1 was obtained.

[0063] Then, GdBCO was deposited as the superconducting layer by PLD on the intermediate layer. Thus, the superconducting wire of Example 1 was obtained.

(Comparative Example 1)

[0064] A substrate and a superconducting wire were obtained in a manner similar to those of Example 1 set forth above, provided that the Ni layer was not subjected to thermal treatment.

(Comparative Example 2)

[0065] A substrate and a superconducting wire were obtained in a manner similar to those of Example 1 set forth above, provided that the Ni layer was subjected to thermal treatment for 30 minutes.

(Measurement Method)

[0066] For the substrates of Example 1 and Comparative Examples 1 and 2, the thickness of each of the Ni layer, Cu-Ni layer (allow layer), and Cu layer, as well as the biaxial orientation of the CeO_2 thin film were measured. Furthermore, the hysteresis loss was measured for the superconducting wire of Example 1 and Comparative Examples 1 and 2. The results are shown in Table 1 set forth below.

[0067] The thickness of each layer in the substrate was measured by EPMA (Electron Probe Micro-Analyzer).

[0068] With regard to the c-axis orientation of the CeO_2 thin film on the substrate, the X-ray diffraction peak intensity from the (200) plane and (111) plane of the CeO_2 thin film (I (200) and I (111)) was measured. The c-axis orientation of the CeO_2 thin film was evaluated by the numeric value of (I (200)/(I (200) + (111)). A higher numeric value implies a higher c-axis orientation of the CeO2 thin film qualified as the intermediate layer, and is preferable. The X-ray diffraction peak intensity from the (200> plane represents the amount of crystals oriented in the direction where the <100> axis is perpendicular to the substrate face. The X-ray diffraction peak intensity from the (111) plane represents the amount of crystals uniaxially oriented in the direction where the <111> axis is perpendicular to the substrate face.

[0069] With regard to the hysteresis loss of the superconducting wire, a magnetic field was applied in a direction parallel to the tape face of the superconducting wire at room temperature. The hysteresis loss thereof was measured using a vibrating sample magnetometer (VSM).

(Measurement Results)

[0070]

Table 1

		Comparative Examples 1	Comparative Examples 2	Examples 1
Thermal Treatment Temperature		Not Treated	850-1000°C	850-1000°C
Thermal Treatment Duration		-	30 minutes	15 minutes
Substrate Structure After Thermal Treatment	Ni layer	2.4 μm	0 μm	1.3 μm
	Cu-Ni layer	0 μm	3 μm	1.7 μm
	Cu layer	18 μm	17.4 μm	17.5 μm
	SUS layer	100 μm	100 μm	100 μm
Hysteresis Loss		53 J/m^3	0 J/m^3	15 J/m^3
C-axis orientation of CeO_2 thin film (I (200)/I (200)+I (111))×100)		95%	50%	95%

[0071] By subjecting the Ni layer to thermal treatment for 15 minutes as in Example 1, a Cu-Ni alloy layer of 1.7 μm in thickness was formed while leaving an Ni layer of 1.3 μm in thickness. By the results of EPMA analysis, it was confirmed that the Ni concentration in the alloy layer decreased monotonically from the interface between the alloy layer and the nickel layer towards the interface between the alloy layer and the copper layer. The CeO_2 thin film had a favorable biaxial orientation since the Cu and Ni were alloyed only partially, and Cu did not diffuse to the surface of the Ni layer. Furthermore, the hysteresis loss could be reduced as compared to Comparative Example 1 not having the Ni layer subjected to thermal treatment.

[0072] In Comparative Example 1, Ni and Cu were not alloyed since the Ni layer was not subjected to thermal treatment. Therefore, the hysteresis loss of the superconducting wire was considerable.

[0073] In Comparative Example 2, Ni and Cu were completely alloyed by the thermal treatment on the Ni layer carried out for 30 minutes. Therefore, the hysteresis loss of the superconducting wire was reduced. However, since Cu was diffused to the surface of the Ni layer, the biaxial orientation of the CeO_2 thin film was degraded as compared to Comparative Example 1 where the Ni layer was not subjected to thermal treatment.

[0074] It is to be understood that the embodiments and examples disclosed herein are only by way of example, and not to be taken by way of limitation. The scope of the present invention is not limited by the description above, but rather by the terms of the appended claims, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

REFERENCE SIGNS LIST

[0075] 1 substrate; 2 copper layer: 3 alloy layer; 4 nickel layer; 5 intermediate layer; 6 superconducting layer; 7 superconducting wire.

Claims

1. A substrate (1) comprising:

- a copper layer (2),
- an alloy layer (3) containing copper and nickel, formed on said copper layer (2),
- a nickel layer (4) formed on said alloy layer (3), and
- an intermediate layer (5) formed on said nickel layer (4),

wherein a concentration of nickel in said alloy layer (3) at an interface between said alloy layer (3) and said nickel layer (4) is greater than the concentration of nickel in said alloy layer (3) at the interface between said alloy layer (3) and said copper layer (2),
characterized in that the alloy layer (3) has a thickness of 1.0 to 2.1 μm.

2. The substrate (1) according to claim 1, wherein the concentration of nickel in said alloy layer (3) decreases monotonically from the interface between said alloy layer (3) and said nickel layer (4) towards the interface between said alloy layer (3) and said copper layer (2).

3. A method of producing a substrate (1), comprising the steps of:

- preparing a substrate having a nickel layer (4) formed on a copper layer (2) through plating,
- alloying a portion of said nickel layer (4) while leaving a remaining portion of said nickel layer (4), and
- epitaxial-growing an intermediate layer (5) on said nickel layer (4) after the step of alloying said nickel layer (4) **characterized in that** the alloying is carried out by subjecting the nickel layer (4) to thermal treatment for 15 to 25 minutes at 800 to 1000 °C.

4. The method of producing a substrate (1) according to claim 3, wherein the step of alloying said nickel layer (4) is carried out under reduced pressure, absent of hydrogen gas.

5. A superconducting wire (7) comprising:

- a copper layer (2),
- an alloy layer (3) containing copper and nickel, formed on said copper layer (2),
- a nickel layer (4) formed on said alloy layer (3),
- an intermediate layer (5) formed on said nickel layer (4), and
- a superconducting layer (6) formed on said intermediate layer (5),

wherein a concentration of nickel in said alloy layer (3) at an interface between said alloy layer (3) and said nickel layer (4) is greater than the concentration of nickel in said alloy layer (3) at the interface between said alloy layer (3) and said copper layer (2), and the alloy layer (3) has a thickness of 1.0 to 2.1 μm.

6. The superconducting wire (7) according to claim 5, wherein the concentration of nickel in said alloy layer (3) decreases monotonically from the interface between said alloy layer (3) and said nickel layer (4) towards the interface between said alloy layer (3) and said copper layer (2).

7. A method of producing a superconducting wire (7) comprising the steps of:

- preparing a substrate having a nickel layer (4) formed on a copper layer (2) through plating,
- alloying a portion of said nickel layer (4) while leaving a remaining portion of said nickel layer (4) by subjecting the nickel layer (4) to thermal treatment for 15 to 25 minutes at 800 to 1000 °C,
- epitaxial-growing an intermediate layer (5) on said nickel layer (4) after said step of alloying said nickel layer (4), and
- forming a superconducting layer (6) on said intermediate layer (5).

8. The method of producing a superconducting wire (7) according to claim 7,
wherein the step of alloying said nickel layer (4) is carried out under reduced pressure, absent of hydrogen gas.

Patentansprüche

1. Substrat (1), umfassend:

- eine Kupferschicht (2),
- eine Legierungsschicht (3), die Kupfer und Nickel enthält und auf der Kupferschicht (2) ausgebildet ist,
- eine Nickelschicht (4), die auf der Legierungsschicht (3) ausgebildet ist, und
- eine Zwischenschicht (5), die auf der Nickelschicht (4) ausgebildet ist,

wobei eine Konzentration von Nickel in der Legierungsschicht (3) an einer Grenzfläche zwischen der Legierungsschicht (3) und der Nickelschicht (4) größer ist als die Konzentration von Nickel in der Legierungsschicht (3) an der Grenzfläche zwischen der Legierungsschicht (3) und der Kupferschicht (2),
dadurch gekennzeichnet, dass die Legierungsschicht (3) eine Dicke von 1,0 bis 2,1 μm aufweist.

2. Substrat (1) nach Anspruch 1, wobei die Konzentration von Nickel in der Legierungsschicht (3) gleichmäßig von der Grenzfläche zwischen der Legierungsschicht (3) und der Nickelschicht (4) in Richtung der Grenzfläche zwischen der Legierungsschicht (3) und der Kupferschicht (2) abnimmt.

3. Verfahren zum Herstellen eines Substrats (1), umfassend die Schritte:

- Herstellen eines Substrats, das eine Nickelschicht (4) aufweist, die auf eine Kupferschicht (2) aufgalvanisiert wird,
- Legieren eines Abschnitts der Nickelschicht (4), während ein verbleibender Abschnitt der Nickelschicht (4) zurückbleibt, und
- epitaxiales Aufwachsen einer Zwischenschicht (5) auf der Nickelschicht (4) nach dem Schritt des Legierens der Nickelschicht (4),

dadurch gekennzeichnet, dass das Legieren ausgeführt wird, indem die Nickelschicht (4) einer 15- bis 25-minütigen Wärmebehandlung bei 800 bis 1000°C unterzogen wird.

4. Verfahren zum Herstellen eines Substrats (1) nach Anspruch 3, wobei der Schritt des Legierens der Nickelschicht (4) unter reduziertem Druck und bei Abwesenheit von Wasserstoffgas ausgeführt wird.

5. Supraleitender Draht (7), umfassend:

- eine Kupferschicht (2),
- eine Legierungsschicht (3), die Kupfer und Nickel enthält und auf der Kupferschicht (2) ausgebildet ist,
- eine Nickelschicht (4), die auf der Legierungsschicht (3) ausgebildet ist,
- eine Zwischenschicht (5), die auf der Nickelschicht (4) ausgebildet ist, und
- eine supraleitende Schicht (6), die auf der Zwischenschicht (5) ausgebildet ist,

wobei eine Konzentration von Nickel in der Legierungsschicht (3) an einer Grenzfläche zwischen der Legierungsschicht (3) und der Nickelschicht (4) größer ist als die Konzentration von Nickel in der Legierungsschicht (3) an der Grenzfläche zwischen der Legierungsschicht (3) und der Kupferschicht (2), und die Legierungsschicht (3) eine Dicke von 1,0 bis 2,1 μm aufweist.

6. Supraleitender Draht (7) nach Anspruch 5, wobei die Konzentration von Nickel in der Legierungsschicht (3) gleichmäßig von der Grenzfläche zwischen der Legierungsschicht (3) und der Nickelschicht (4) in Richtung der Grenzfläche zwischen der Legierungsschicht (3) und der Kupferschicht (2) abnimmt.

7. Verfahren zum Herstellen eines supraleitenden Drahtes (7), umfassend die Schritte:

- Herstellen eines Substrats, das eine Nickelschicht (4) aufweist, die auf eine Kupferschicht (2) aufgalvanisiert wird,
- Legieren eines Abschnitts der Nickelschicht (4), während ein verbleibender Abschnitt der Nickelschicht (4) zurückbleibt, indem die Nickelschicht (4) einer 15- bis 25-minütigen Wärmebehandlung bei 800 bis 1000°C unterzogen wird,
- epitaxiales Aufwachsen einer Zwischenschicht (5) auf der Nickelschicht (4) nach dem Schritt des Legierens der Nickelschicht (4), und
- Bilden einer supraleitenden Schicht (6) auf der Zwischenschicht (5).

8. Verfahren zum Herstellen eines supraleitenden Drahtes (7) nach Anspruch 7, wobei der Schritt des Legierens der Nickelschicht (4) unter reduziertem Druck und bei Abwesenheit von Wasserstoffgas ausgeführt wird.

Revendications

1. Substrat (1) comprenant :

- une couche de cuivre (2),
- une couche d'alliage (3) contenant du cuivre et du nickel, formée sur ladite couche de cuivre (2),
- une couche de nickel (4) formée sur ladite couche d'alliage (3), et
- une couche intermédiaire (5) formée sur ladite couche de nickel (4),

dans lequel la concentration de nickel dans ladite couche d'alliage (3) à l'interface entre ladite couche d'alliage (3) et ladite couche de nickel (4) est supérieure à la concentration de nickel dans ladite couche d'alliage (3) à l'interface entre ladite couche d'alliage (3) et ladite couche de cuivre (2),
caractérisé en ce que la couche d'alliage (3) a une épaisseur de 1,0 à 2,1 μm.

2. Substrat (1) selon la revendication 1, dans lequel la concentration de nickel dans ladite couche d'alliage (3) diminue de façon monotone depuis l'interface entre ladite couche d'alliage (3) et ladite couche de nickel (4) en direction de l'interface entre ladite couche d'alliage (3) et ladite couche de cuivre (2).

3. Procédé de production d'un substrat (1), comprenant les étapes de :

- préparation d'un substrat ayant une couche de nickel (4) formée sur une couche de cuivre (2) par placage,
- alliage d'une partie de ladite couche de nickel (4) cependant qu'une partie restante de ladite couche de nickel (4) est maintenue, et
- croissance épitaxiale d'une couche intermédiaire (5) sur ladite couche de nickel (4) après l'étape d'alliage de ladite couche de nickel (4),

caractérisé en ce que l'alliage est effectué par soumission de la couche de nickel (4) à un traitement thermique pendant 15 à 25 minutes à une température de 800 à 1 000 °C.

4. Procédé de production d'un substrat (1) selon la revendication 3, dans lequel l'étape d'alliage de ladite couche de nickel (4) est effectuée sous pression réduite, en l'absence d'hydrogène gazeux.

5. Fil supraconducteur (7) comprenant :

- une couche de cuivre (2),
- une couche d'alliage (3) contenant du cuivre et du nickel, formée sur ladite couche de cuivre (2),
- une couche de nickel (4) formée sur ladite couche d'alliage (3),
- une couche intermédiaire (5) formée sur ladite couche de nickel (4), et
- une couche supraconductrice (6) formée sur ladite couche intermédiaire (5),

dans lequel la concentration de nickel dans ladite couche d'alliage (3) à l'interface entre ladite couche d'alliage (3) et ladite couche de nickel (4) est supérieure à la concentration de nickel dans ladite couche d'alliage (3) à l'interface entre ladite couche d'alliage (3) et ladite couche de cuivre (2), et la couche d'alliage (3) a une épaisseur de 1, 0 à 2, 1 μm.

6. Fil supraconducteur (7) selon la revendication 5, dans lequel la concentration de nickel dans ladite couche d'alliage (3) diminue de façon monotone depuis l'interface entre ladite couche d'alliage (3) et ladite couche de nickel (4) en direction de l'interface entre ladite couche d'alliage (3) et ladite couche de cuivre (2).

7. Procédé de production d'un fil supraconducteur (7), comprenant les étapes de :

- préparation d'un substrat ayant une couche de nickel (4) formée sur une couche de cuivre (2) par placage,
- alliage d'une partie de ladite couche de nickel (4) cependant qu'une partie restante de ladite couche de nickel (4) est maintenue, par soumission de la couche de nickel (4) à un traitement thermique pendant 15 à 25 minutes à une température de 800 à 1 000 °C,
- croissance épitaxiale d'une couche intermédiaire (5) sur ladite couche de nickel (4) après ladite étape d'alliage de ladite couche de nickel (4), et
- formation d'une couche supraconductrice (6) sur ladite couche intermédiaire (5).

8. Procédé de production d'un fil supraconducteur (7) selon la revendication 7, dans lequel l'étape d'alliage de ladite couche de nickel (4) est effectuée sous pression réduite, en l'absence d'hydrogène gazeux.

FIG.1

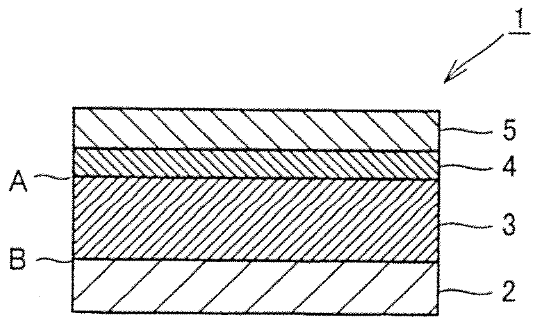


FIG.2

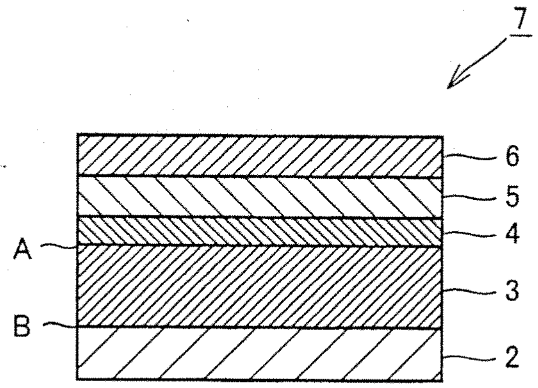


FIG.3

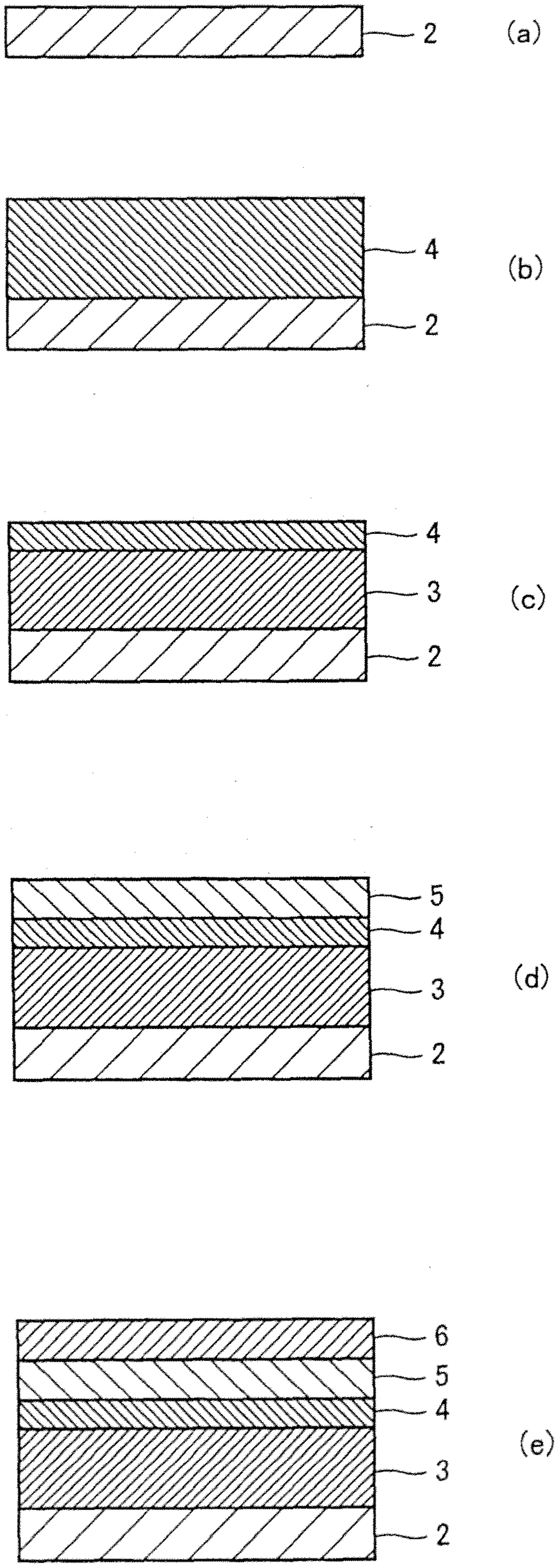
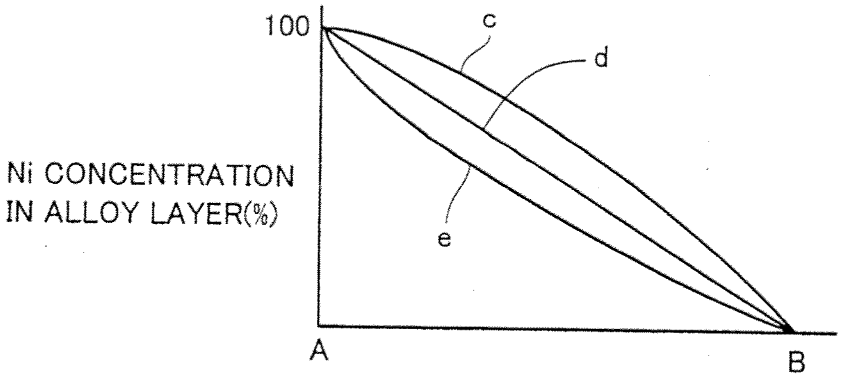
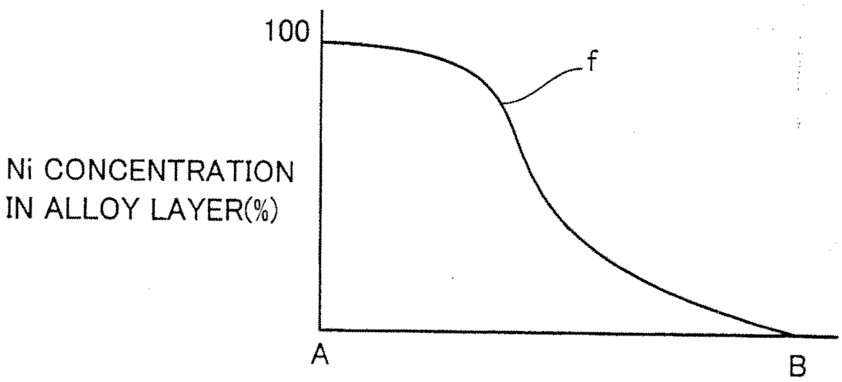


FIG.4


100
c
d
e
Ni CONCENTRATION
IN ALLOY LAYER(%)
A
B

(a)


100
f
Ni CONCENTRATION
IN ALLOY LAYER(%)
A
B

(b)

REFERENCES CITED IN THE DESCRIPTION

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